THE COMMUNITY SEDIMENT TRANSPORT MODELING SYSTEM

W. Rockwell Geyer
Woods Hole Oceanographic Institution
MS 11, Woods Hole, MA 02543
phone: 508-289-2868 fax: 508-457-2194 email: rgeyer@whoi.edu

Christopher R. Sherwood
U. S. Geological Survey
384 Woods Hole Road, Woods Hole, MA 02543-1598
Phone: (508) 457-2269 Fax: (508) 457-2310 email: csherwood@usgs.gov

Timothy Keen
Naval Research Laboratory, Code 7322, Stennis Space Center, Mississippi, 39529
phone: (228) 688-4950 fax: (228) 688-4759 email: timkeen@charter.net
Document Number: N0001406WX21379
http://www7300.nrlssc.navy.mil
http://www.cstms.org/

Award Number: N00014-06-1-0945

LONG-TERM GOALS

The goal of the Community Sediment Transport Modeling System (CSTMS) is to produce an open-source model that couples hydrodynamics (circulation and waves), sediment transport, and morphodynamics. The model is intended to be used as both a research tool and for practical applications. An accurate and useful model requires coupling sediment-transport with hydrodynamic forcing and stratigraphic evolution. Ultimately, the modeling system will consist of interoperable modules, conforming to a community-accepted standard such as the Earth System Modeling Framework (ESMF).

OBJECTIVES

The specific objectives that have been addressed this year include:

- developing sediment-transport modules, testing them with stand-alone modules, and incorporating them into the Regional Ocean Modeling System (ROMS) and stand-alone modules;
- incorporating hydrodynamic processes into ROMS that are essential for quantitative sediment-transport modeling;
- developing ESMF-compatible model coupling of components of CSTMS modules;
- developing and distributing tools for model development and testing;

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **The Community Sediment Transport Modeling System**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institute,98 Water Street,Woods Hole,MA,02543**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**16**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

- documenting the sediment transport algorithms and maintaining a collaborative site for distribution, documentation, tutorials, algorithms and user-support software, test problems, analysis tools, discussion forum, and outreach;
- applying CSTMS to specific field environments.

APPROACH AND WORK PLAN

The team includes a large group of sediment-transport specialists, hydrodynamicists, and numerical modelers (Table 1). The team communicates via annual meetings, Webex meetings, and sub-group interactions. The core of the project involves design and implementation of the modular model framework, development of standards and conventions for data exchange and tools for pre- and post-processing and analysis, and development of modules from new sediment-transport algorithms. A collaborative web site hosting code, test cases, documentation, and discussions was established early in the project and is continually updated by program participants (https://www.myroms.org/projects/cstm). Finally, use of the model in real-world applications is being conducted by the Partner Investigators and others.

Table 1: The CSTMS Team

Organization	Personnel	Oversight and management	Module development	Software tools	Algorithm development	Community engagement	Model application
Woods Hole Oceanographic Institution	R. Geyer J. Trowbridge P. Traykovski	X			X		X
U.S. Geological Survey Coastal and Marine Geology Program	C. Sherwood R. Signell J. Warner B. Butman	X	X	X	X	X	X
Naval Research Lab (Stennis)	T. Keen T. Campbell	X	X		X		X
U.S. Army Corps of Engineers (ERDC)	D. Resio J. Hanson	X	X	X	X		X
HR Wallingford	R. Soulsby R. Whitehouse	X	X		X		X
Mississippi State University	S. Bhate	X		X		X	
Ohio State University	D. Foster J. Fredsoe	X			X		X
Oregon State University	E. Skyllingstad N. Perlin		X				
Rosenstiel School of Marine and Atmospheric Science	Y. Chang				X		
Rutgers University (Academic)	H. Arango D. Robertson	X	X			X	
Stevens Institute	A. Blumberg	X			X		
UNESCO-IHE	D. Roelvink	X					X

University of California, Los Angeles	J. McWilliams Y. Uchiyama	X	X		X		X
University of Delaware	J. Kirby F. Shi T. Hsu	X	X		X X		
University of Maryland	L. Sanford				X		X
WL|Delft Hydraulics Laboratory	B. Jagers J. Winterwerp	X					

RESULTS

1. Enhancements to ROMS supported by CSTMS

A robust version of ROMS (3.1) that includes circulation, waves, sediment transport, and morphology is on line and available to the public. A new version of ROMS (version 3.2) is under development. This new version of the code includes multi-model coupling of ROMS, SWAN, WRF, and the CSTMS sediment-transport routines using the Model-Coupling Toolkit (MCT) and multi-grid nesting (composite, mosaic, and refined) capabilities. An Earth System Modeling Framework (ESMF) driver was developed to couple ROMS to other models. This driver uses the ESMF superstructure to control the flow of data between all models. We interacted with the ESMF developers to also allow direct coupling (no super-structure control) within the ESMF library. This will enable volumetric coupling within the ROMS computational kernel without the need to split the code into different routines to meet superstructure requirements.

<u>Composite Grids</u>

The composite and mosaic grid attributes of ROMS version 3.2 are designed to increase the effectiveness of ROMS in regions of complex topography. We have developed a method of connecting sub-domains to the overall simulation, passing information both ways to the adjacent domains so that the calculation is equivalent to a single, integrated domain (Figure 1). The advantage of this approach is that it allows arbitrary overall geometry, although each individual segment is rectangular. The approach is being generalized to accomplish two-way nesting for localized grid refinement.

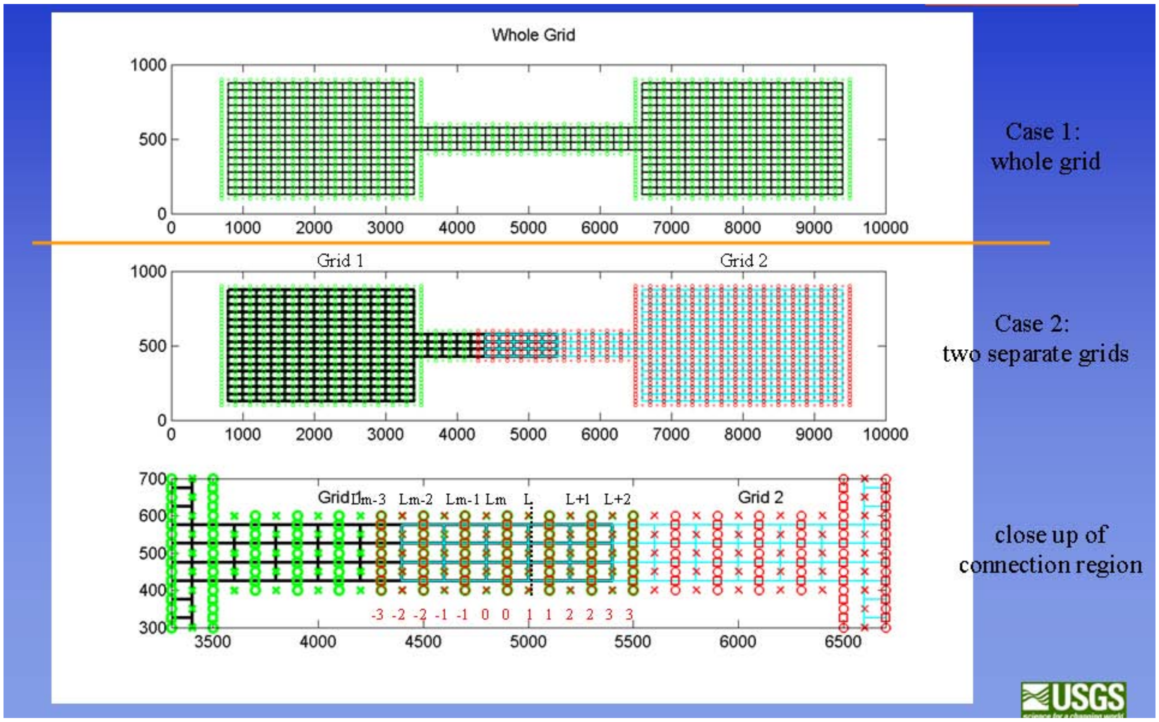

Figure 1. The "dog-bone" test case of the composite grid algorithm being implemented in ROMS 3.2. This test case compares the solution from a single continuous grid (Case 1, top panel) to a composite grid of the same system (Case 2, middle panel). The connection of the composite grids is enlarged (bottom panel). The solutions to Cases 1 and 2 are indistinguishable.

Wave-Current Interactions

Two different wave-current interaction formulations are under development as part of CSTMS. The Mellor (2005) formulation was implemented by Warner (Warner et al. 2008a, b). Testing of this formulation against observations at the Martha's Vineyard Coastal Observatory and the Sandy Duck experiment yielded excellent agreement in the wave-induced transport (Figure 2), providing support for this approach.

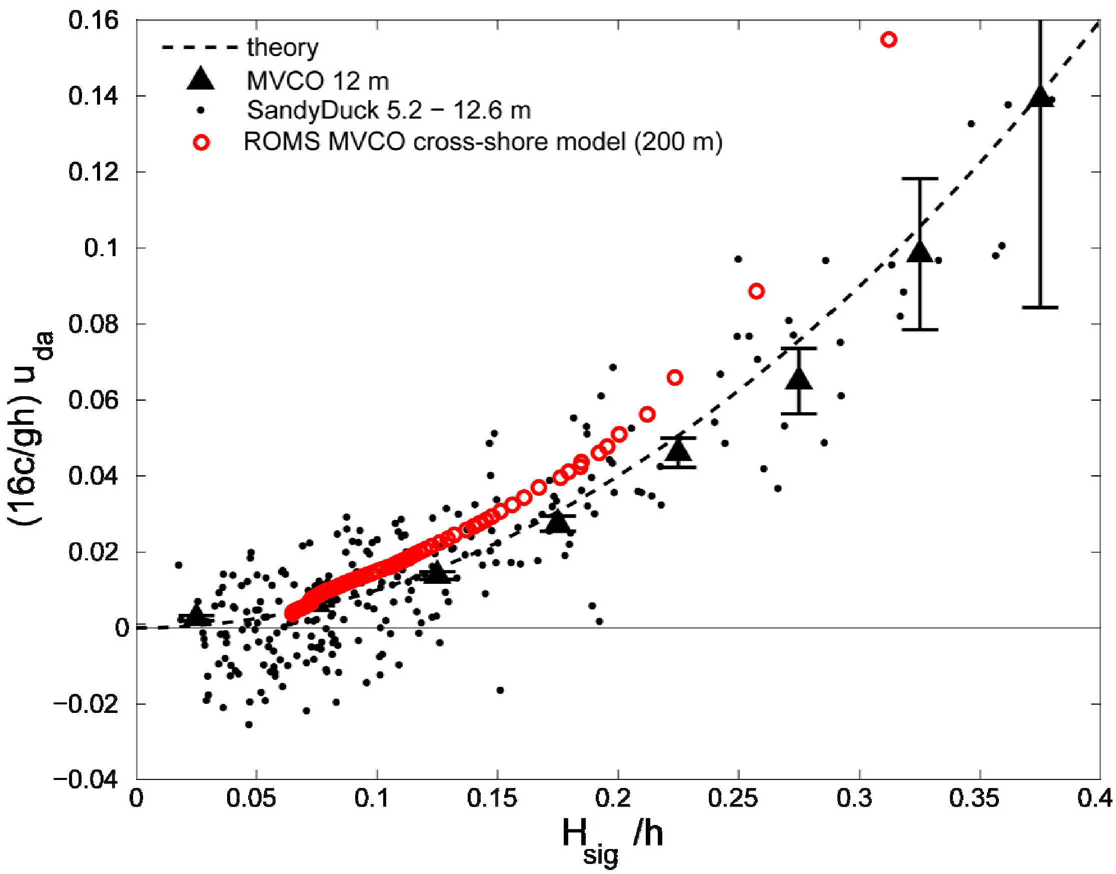

Figure 2. Results of the wave-current interaction formulation of Mellor (2005) as implemented by Warner et al (2008 a, b) compared with Stokes theory and observations of Lentz et al. (in press). The x-axis is the significant wave height normalized by the water depth, and the y-axis is the observed and modeled wave-momentum flux (normalized by the local wave propagation speed).

The UCLA group is also addressing wave-current interaction, based on the vortex-force formalism by McWilliams et al. (2004), extended for application to strong currents and wave-breaking applicable to wave-driven nearshore currents within and near surf zones. A set of WKB wave ray and action conservation equations, a roller energy conservation equation (Svendsen, 1994) that describes breaking-wave-driven inshore-traveling bore, referred to as a surface roller, and current and tracer equations with wave-current interaction has been implemented in ROMS with appending non-conservative parameterization to account for wave energy loss due to depth-induced wave breaking proposed by Thornton and Guza (1986). The KPP vertical eddy viscosity/diffusivity submodel (Large et al., 1984) in ROMS has also been modified to incorporate effects of breaking waves. An investigation of littoral currents driven by incident gravity waves in depth-averaged

configurations on a single barred beach topographies relevant to a natural sandy beach at Duck, NC, has been carried out (Uchiyama et al., 2008). Roles played by wave-current interaction are investigated for so-called shear waves i.e., low-frequency fluctuating motions associated with nearshore shear instability in alongshore currents (Figure 3). A full three-dimensional wave-current interaction model has also been developed and is being extensively tested with a surf-zone scale Duck-type configuration and with an inner-shelf-scale, rotating and stratified configuration to be tested with measurements near Martha's Vineyard.

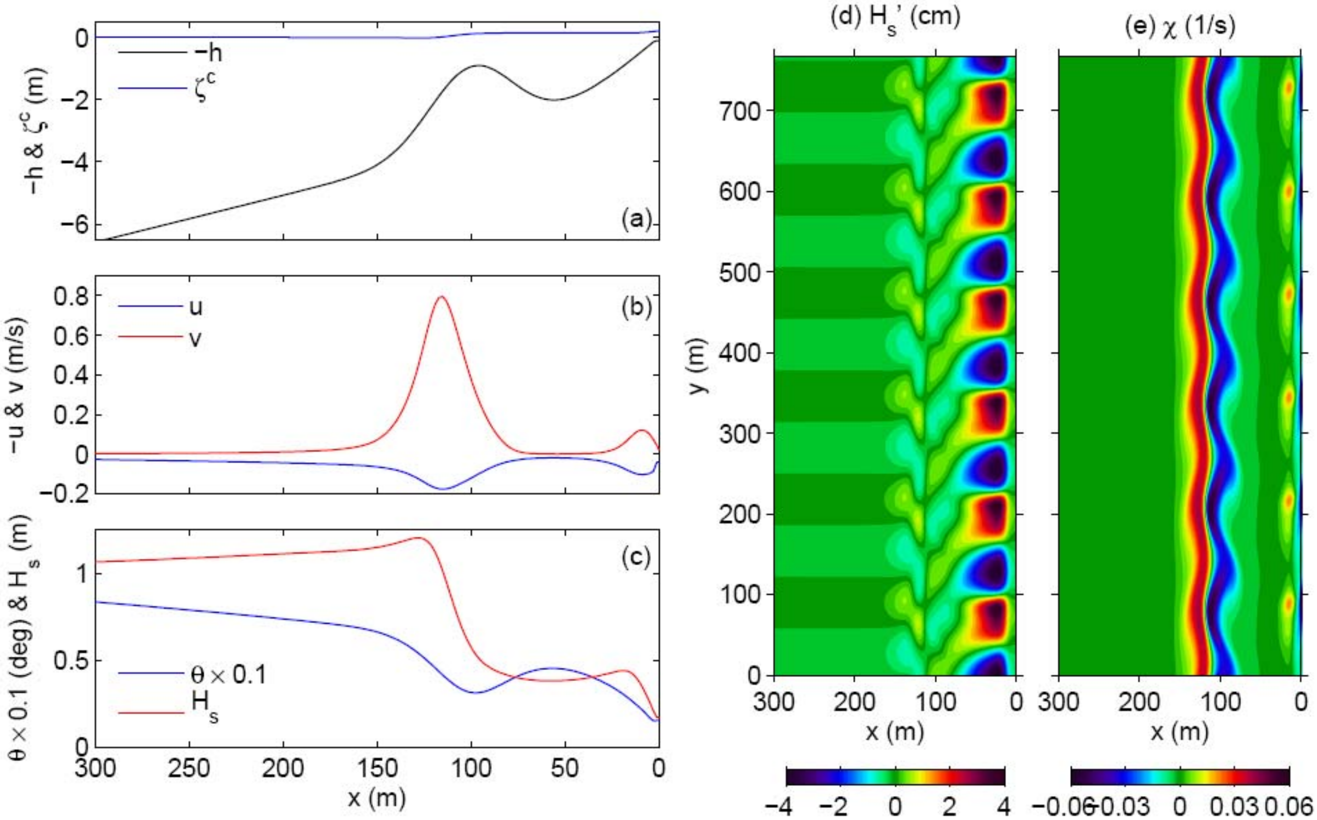

Figure 3. Example of wave-current interaction in littoral-current shear instability on an idealized barred beach in a marginally unstable flow regime. Cross-shore profiles of time- and alongshore-averaged (a) sea surface elevation ς_c and depth $-h$, (b) shoreward and poleward velocity components u and v, (c) wave direction θ and R.M.S. wave height H_s. Also shown are plan-view snap-shots of (d) fluctuating component of wave height H'_s and (e) vertical component of relative vorticity χ.

Shoreline Boundary Conditions

Kirby and Shi have implemented in Shorecirc an algorithm for new shoreline boundary conditions with surf-swash interaction. This addresses a common problem that exists in ROMS and virtually all other models: in a wave-averaged model that neglect swash-zone dynamics, the shoreline boundary is specified at the location where the mean total water depth is zero, which may not be consistent with

the actual wave-averaged properties at the swash zone and cannot account for transport of water and sediment above this elevation. Kirby and Shi have redefined the shoreline boundary at the wave run-down position estimated from the residual bore height according to Brocchini and Bellotti (2002). They re-derived the Lagrangian-type wave-averaged equations with shoreline boundary conditions that are consistent with Brocchini and Bellotti's swashzone integrated model. The surf-swash interaction is presented by the mass and momentum exchanges between the surf zone and swash zone at the newly defined shoreline boundary (Shi, Zhu, and Kirby, 2008).

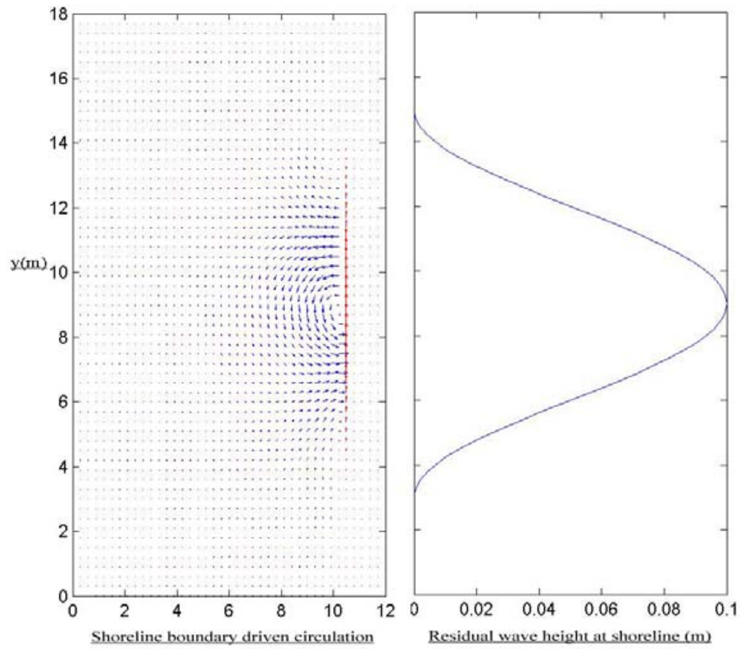

Figure 4. (right) An idealized residual wave height distribution in the longshore direction with 30 degrees of incident wave angle from SE. (left) Circulation driven by the swash zone mass and momentum fluxes at the surfzone-swashzone interface. The red arrows represent alongshore flux integrated over the swashzone.

Kirby and Shi have modified the Refraction/Diffraction wave model to take into account unsaturated breaking waves and to calculate the residual bore height at the newly defined shoreline position. The previous REF/DIF wave model used a depth-limited wave breaking formulation that leads to zero wave height at the shoreline. They added an option that calculates the residual wave height at the newly defined shoreline boundary based on Baldock and Holmes' (1999) formulation. The residual wave height at the shoreline is used to evaluate the swashzone wave runup height as well as the integral hydrodynamic properties in the swash zone.

The swash zone dynamics are modeled using Antuono et al.'s (2007) solutions of integral swash zone properties. The swash zone model also provides the surfzone model with mass and momentum fluxes at the shoreline boundary. Figure 4 shows the results from the surf-swash interaction model with alongshore non-homogenous wave conditions. The right panel shows an idealized residual wave height distribution in the longshore direction. The left panel shows the circulation driven by the swash zone mass and momentum fluxes at the surfzone-swashzone interface. It is shown that swash zone motions strongly influence the circulation patterns in the inner surfzone.

Roelvink and collaborators are also investigating shoreline processes through continued development XBeach, a two-dimensional depth-averaged wave and circulation model for sediment-transport in the nearshore zone that resolves infragravity wave motions and simulates dune erosion, overwash, and breach formation. Key advances this year include coupling with Delft3D, successful prototype simulation of a barrier-beach breach (Figure 5) and incorporation of groundwater interaction with swash.

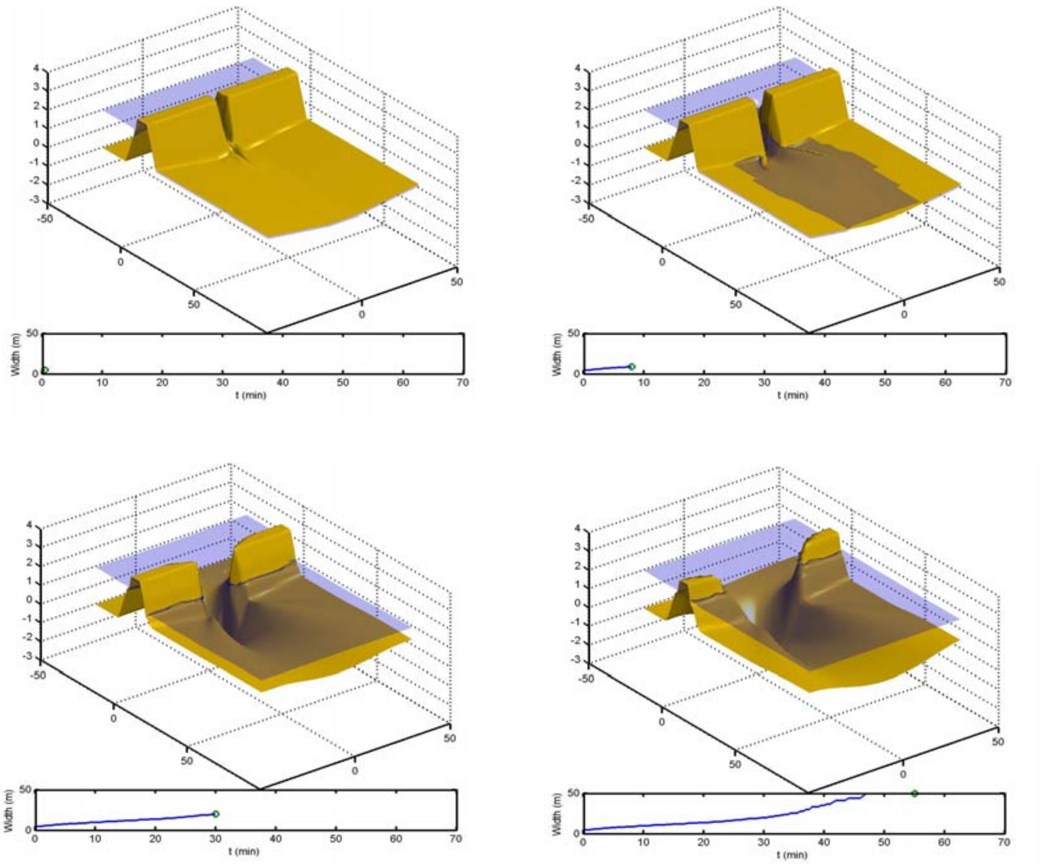

Figure 5. XBeach simulation of enlargement of a dune breach and evolution of the breach into a tidal channel.

Parameterization of Wave-Current Boundary Layer Processes in ROMS using Dune

Foster, Fredsoe, and students have made progress incorporating Dune into the model framework and evaluating the existing CSTMS sub-grid parameterizations. Dune is a quasi-three dimensional model that resolves flow and sediment transport over rough beds. The quasi-three dimensional version of the Dune code is running for arbitrary wave-current angles. They have created a branch within the CSTMS repository for Dune (located at https://svn1.hosted-projects.com/cmgsoft/dune/). Wave-current bottom-boundary layer simulations over a flat, rough bed have been performed for wave-current angles of 0 and 45 degrees. A new morphologic filtering algortim has been incorporated within Dune. Morphologic simulations of ripple evolution from both a flat bed and relic ripple field have been performed. The morphologic routine has allowed for simulation of rippled beds from both flat and relic rippled state (Figure 6). When simulations are performed from random bed forms, the bed growth rate

is consistent with laboratory observations. The new morphology module allows for the calculation of the wave energy dissipation as the bed evolves. The simulations above random bed forms confirm that the ripple steepness is the main cause of energy dissipation.

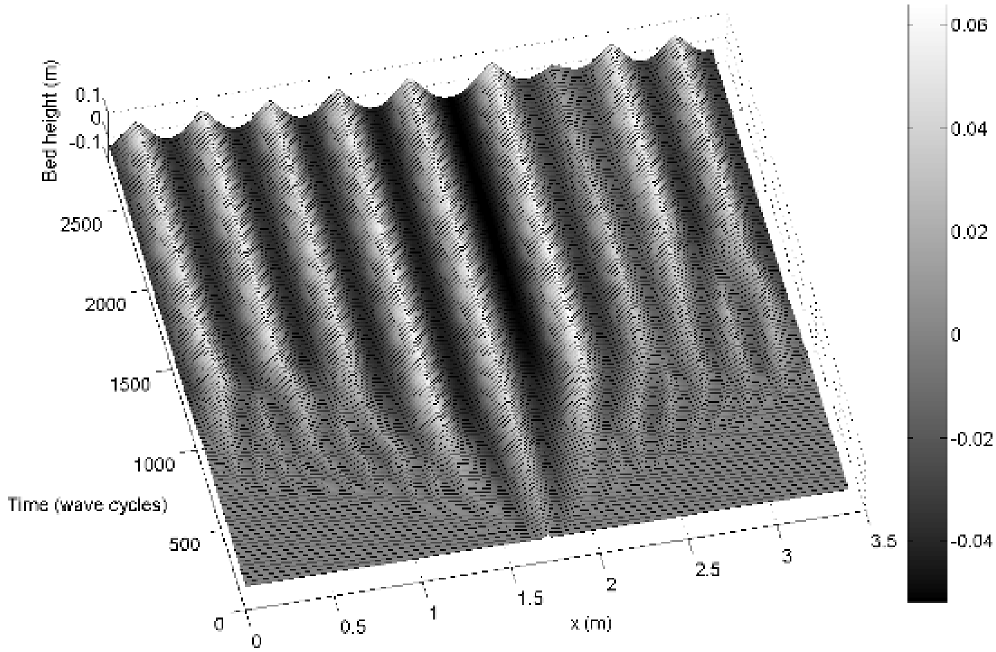

Figure 6. Evolution of an initially flat bed into linear ripples during a Dune simulation of wave-current bottom boundary layer flow.

Optics

Keen is developing an algorithm to estimate suspended sediment concentrations in surface water using channel 6 (660-680 nm) SeaWiFS data and has completed an algorithm for estimating water-column scattering by suspended sediment. These can function as stand-alone modules that may help evaluate model results.

2. New Sediment-Transport Algorithms for ROMS

CSTMS investigators are working on a diverse set of sediment-transport modeling problems; here we highlight several of the emerging modeling developments supported by CSTMS.

Modeling wave-supported gravity flows Hsu has developed a stand-alone model to investigate the vertical structure of wave-supported gravity flows such as those documented by Traykovski et al. (2007) on the California shelf and Po pro-delta. A high-resolution, one-dimensional model that resolves the phase of the forcing gravity waves is being used to test the hypothesized mechanisms controlling the vertical distribution of sediment within the wave boundary layer and the resulting cross-shelf transport. In addition to wave processes, the model includes the influence of flocculation, hindered settling, rheology, and turbulence-suppression by stratification. Figure 7 indicates that the model effectively captures the vertical structure of the suspended sediment distribution and the

magnitude of the velocity (as well as can be characterized by available data). The analysis indicates that the intra-wave variability of stress is not crucial to the overall prediction of time-averaged concentration and velocities, because the settling timescale (i.e., wave boundary layer thickness divided by settling velocity, which is around 10 minutes) is in general much larger than the wave period (~10 sec). This offers some promise that a wave-averaged approach required in a ROMS implementation is feasible. However, there remain significant challenges. Rheology is an important part of the dynamics for higher concentration suspensions. For lower concentration conditions, the fractal dimension for flocs is the key variable controlling the dynamics. At this time the fractal dimension of flocs needs to be specified empirically, and there are few data sets with which to constrain such estimates.

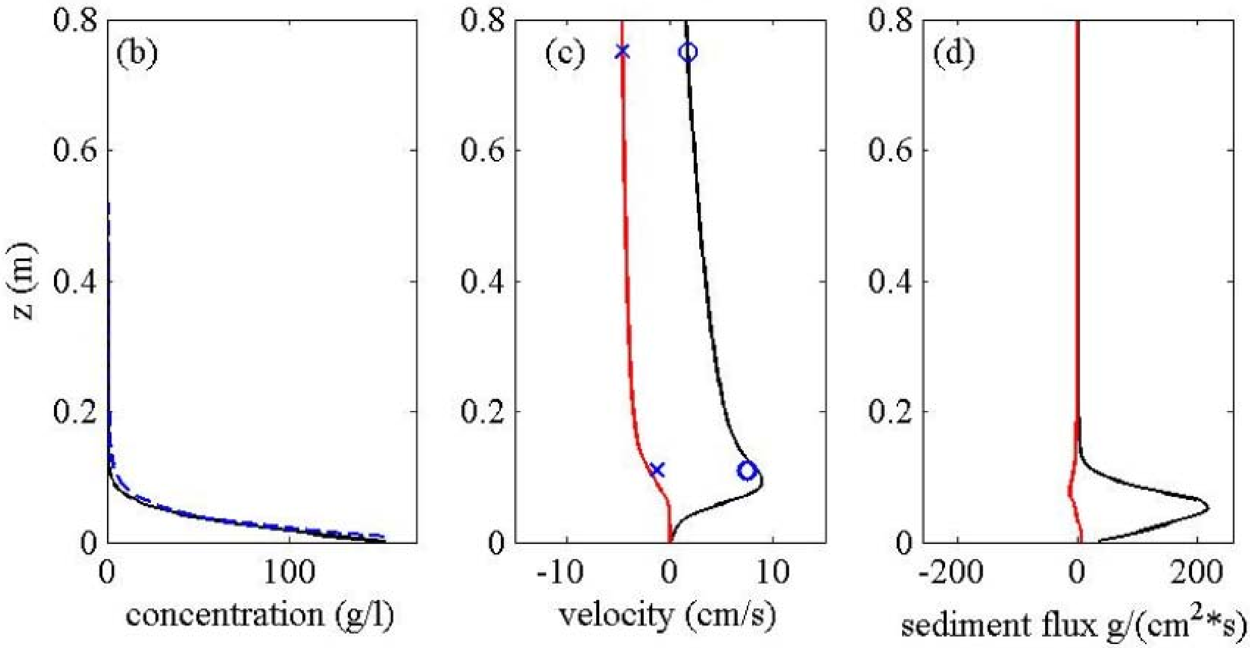

Figure 7. Model-data comparison of wave-supported gravity-driven mudflow for high concentration fluid mud event, from Hsu et al. (submitted). (b) Time-averaged mud concentration with solid curve represents model results and dashed curve represent measured data. (c) Modeled (black-solid curve) and measured (circles) time-averaged cross-shelf velocity profile and long-shelf velocity profile (red-solid: model results, crosses: measured data). (d) Model results on cross-shelf (black-solid) and long-shelf (red-solid) sediment fluxes.

<u>Parameterization of Sediment Entrainment Rate</u>

Chang has been evaluating numerical model output from a large eddy resolving (LES) model of near-bottom flow to parameterize the sediment pickup function associated with small-scale convection. One of the difficulties has been quantifying the pickup rate from model output, and to do this, Chang has been evaluating the ratios of change rates of sediment concentrations near the bed against those slightly farther from the bed. The results are complicated and exhibit strong variation in time, space, and with changes in flow conditions and sediment characteristics, indicating that additional sets of LES model runs will be necessary.

Implementation of Cohesive and Mixed Sediment in ROMS Sherwood and Ferré (USGS) implemented a cohesive-bed formulation for ROMS, with input from Sanford, Warner, and J. Paul Rinehimer (Virginia Institute of Marine Sciences). They incorporated the one-dimensional (vertical) model of Sanford (2007) model into the three-dimensional framework of ROMS. This is an example of the transition process from one-dimensional process models to operational elements in the CSTMS framework. Sherwood and Ferré modified the existing algorithms for tracking stratigraphy in ROMS to include profiles of sediment erodibility τ_{crit}. The model includes time-dependent consolidation and swelling algorithms, in which the profile of τ_{crit} relaxes back to an equilibrium profile after it has been disrupted by erosion or deposition. This implementation included mixed sediment, i.e., cohesive (mud) as well as non-cohesive (sand) fractions, which raised problem of specifying the transition between cohesive and non-cohesive behavior. As there is limited theoretical guidance for this transition, they applied an ad hoc gradation between non-cohesive and cohesive behavior, starting at fully cohesive behavior at 20% mud and fully non-cohesive behavior at 3% mud. The model also included an numerical implementation of solid-phase diffusive mixing for parameterizing biodiffusion at depth-dependent mixing rates that must be specified from data or a model of infaunal activity.

The model has been applied to a number of test cases, and the results are promising. Notably there are few algorithmic difficulties (e.g., numerical stability, logic errors, computational load, etc.), and the most serious issues are related to specification of rates and initial conditions (which are challenging problems). The tests to date include a modulated tidal flow, a sequence of wave events, and an idealized simulation of the western Adriatic shelf in an attempt to reproduce the observed sand-mud transition. The result of the latter simulation indeed produces a migration of the sand-mud transition to the 10-20 m isobath, consistent with observations. Although these tests are preliminary, they indicate an important step toward a prognostic representation of a cohesive and/or mixed sediment bed in the CSTMS implementation of ROMS.

3. CSTMS Tools, Documentation, and Community Involvement

Mississippi State investigator Bhate, with guidance from Signell, developed an advanced regression package for ROMS. This package allows ROMS to run through a suite of simulations that test compiling, linking, configuration and monitors changes in results. In a complex modeling environment, a regression package helps developers find bugs before sending out for user testing, reducing user frustration when a new version arrives and the old configurations no longer work. Because of the modular extensible environment, the package can be configured easily for other tasks, and new users have found it a convenient environment for setting up and running new CSTMS simulations.

The Rutgers team has continued to adding and improve ROMS technical and practical documentation on wikiROMS (https://www.myroms.org/wiki). A ROMS user's workshop was held at the University of California, Los Angeles October 1-3, 2007. This was followed by the CSTMS meeting October 4th and 5th. Several basic training sessions on how to use ROMS were given and recorded (WebEx). The next ROMS user's workshop will be held at Jean Kuntzmann laboratory amphitheater, Saint Martin d'Heres Campus, Grenoble, France on October 6-8, 2008.

4. Applications

The Wallingford team has started developing a regional test case addressing the hydrodynamics, sediment transport and morphological change at Teignmouth (UK), as part of the COAST 3D programme. Three test cases will be developed, including two tidally dominated cases and one case with large wave forcing of nearshore circulation. Everything is in place with information available for the specification of boundary conditions. Some initial work has been completed on developing a ROMS model grid for the Teignmouth inlet but given the complex nature of the coastal geometry, further work is required to optimise the grid in conjunction, with project partners where appropriate, prior to developing the test cases fully.

Warner and Geyer are developing a test case in the Hudson estuary, for which there are extensive cohesive-sediment data for model validation. The effective modeling of this system is greatly facilitated by the composite grid capability for ROMS that has recently been developed. The importance of the composite-grid approach is demonstrated in a passive-tracer release (Figure 8), which is preliminary to the suspended-sediment application.

Warner, working with USGS funding for the Coastal Carolinas Change Processes project, is developing a mutliply nested, coupled application for weather, circulation, waves, sediment-transport and morphologic change off North and South Carolina, focussing on processes that maintain cape shoals. This project is distinct from CSTMS, but benefits from CSTMS development of ROMS and incorporates collaborators including Ruoying He (N. Carolina State), Kevin Haas (Georgia Tech), and George Voulgaris (Univ. of South Carolina).

Sherwood and Neil Ganju (USGS) are developing a nested, coupled application for the region near the Martha’s Vineyard Coastal Observatory, in conjunction with the ONR Ripples DRI project and the OASIS project.

The UCLA group has successfully updated the triple nested regional configuration for the Palos Verdes Shelf encompassing Santa Monica and San Pedro Bays, CA, with a 200-m spatial resolution for non-cohesive sediment transport simulation embedded in the intermediate Southern California Bight domain with 1 km resolution, fed by the outermost U.S. West Coast domain with 5-km resolution (used to be 20 km). Compatible double nested atmospheric modeling with WRF and wind-sea/swell prediction with SWAN have also been accomplished. The extensive upwelling event occurred in March 2002 is better reproduced with evident appearance of submesoscale spiral eddies all over the inner-most domain. The high-resolution inner domain produces shoreline eddies associated

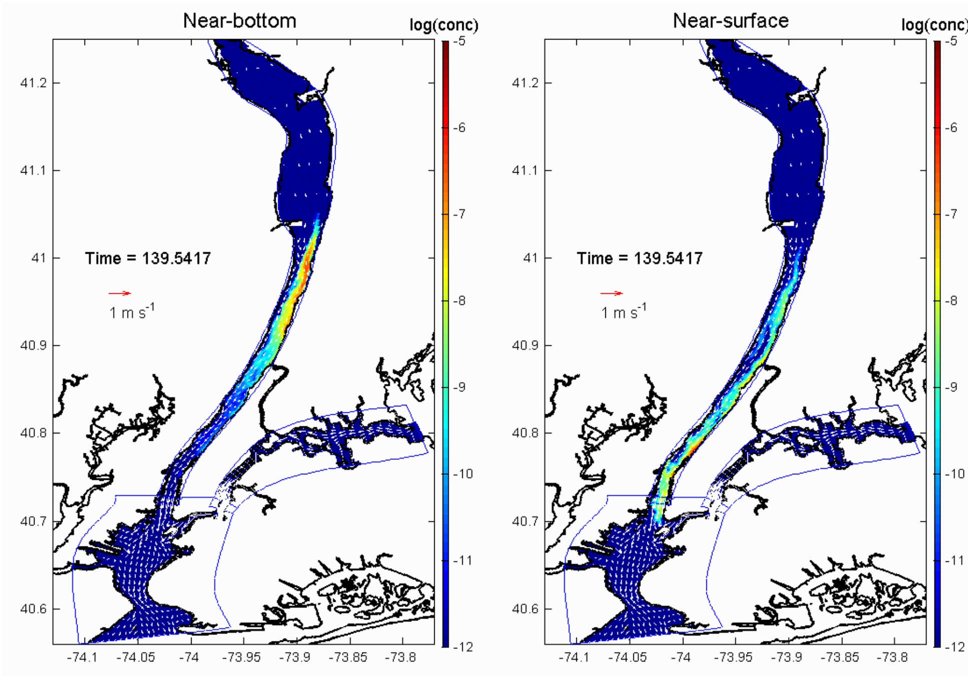

Figure 8. Simulation of passive-tracer releases in the Hudson River estuary, illustrating the effectiveness of the composite-grid technique for simulating complex domains. In the right panel, significant tracer has been transported across the boundary between two sub-domains, with no adverse effects on the computation of scalar transport. This reach of the Hudson is an important field test case for cohesive sediment transport using CSTMS.

with passage of a frontal structure right at the shoreline to form filament patterns in SSS and then to roll up into cohesive submesoscale eddies. These features indicate the critical importance of multiple nesting to provide realistic simulations of sub-mesoscale structure in coastal environments.

5. Model Output Infrastructure

The goal of CSTMS is to eventually support a variety of wave, current and met models in addition to ROMS, SWAN and WRF. Toward that end, Signell and Bhate have developed a procedure and a set of tools for distributing and accessing data from different models with a standards-based approach. The procedure is designed to be simple for model data providers. We standardize using the Climate and Forecast (CF) conventions, but instead of forcing providers to rewrite their output files, the output files are standarized at a central server via NcML, an XML markup langauge which can repair or add metadata to meet the CF conventions. The data are then available through a THREDDS Data Server via OpenDAP. OpenDAP with CF Conventions is the only existing web service that is capable of serving the model output from the types of native grids commonly used for coastal models (e.g. curvilinear horizontal coordinates, sigma or s-coordinate systems) in a standardized form. We are building an object oriented toolkit for Matlab that reads CF-compliant data from OpenDAP, and have demonstrated that we can read 3D georeferenced data from POM, ROMS, SWAN, WRF, ECOM and WaveWatch 3 all with the identical model-neutral Matlab command. Using this approach, the CSTMS model results can also be accessed by software developed wholly outside of CSTMS, like the Unidata's Integrated Data Viewer, or the Reading E-Science Centre ncWMS server/GODIVA2 client. This standards-based approach has application well beyond CSTMS and is likely to be adopted by the

NOAA IOOS Data Integration Framework for harmonizing access to model output from the National Backbone and from the Regional Associations.

IMPACT AND APPLICATIONS

CSTMS provides a starting point for a wide range of numerical investigations. It is a tool for scientists who are interested in coastal and estuarine processes and need the numerical context of a high-quality physical oceanographic model. The physical oceanographic model ROMS and the non-cohesive sediment-transport algorithms in the CSTMS associated with ROMS are sufficiently mature for a wide range of applications, and are being actively used by researchers worldwide.

TRANSITIONS

Researchers not funded by the NOPP project are presently using the model in the Adriatic Sea, Chesapeake Bay, Louisiana, and other locations.

RELATED PROJECTS

Testing and application of the CSTMS has benefited, or will benefit, from field measurements obtained during ONR STRATAFORM., EuroSTRATAFORM, the Mine Burial Experiment, CBLAST, the Ripples DRI, SandyDuck, NCEX, the Mud Flats DRI, and the Coherent Structures MURI. Data from USGS projects in Massachusetts Bay, Vineyard Sound, South Carolina and Palos Verdes have been used, as have data from the NSF and Hudson River Foundation studies in the Hudson River. The model has been informed by process studies conducted as part of Nearshore NOPP project, OASIS, the Ripples DRI, CBLAST, Hudson River studies, and various USGS and NRL projects. This project parallels the USACOE Morphos project, and will provide a template and model modules for the NSF CSDMS project.

REFERENCES

Antuono M., Brocchini M., and Grosso G., 2007, Integral flow properties of the swash zone and averaging. Part 3. Longshore shoreline boundary conditions for wave-averaged nearshore circulation models, J. Fluid Mech., vol 573, pp. 399-415.

Baldock T. E. and Holmes P., 1999, Simulation and prediction of swash oscillations on a steep beach, Coast. Eng. 36, 219-242.

Brocchini M. and Bellotti G., 2002, Integral flow properties of the swash zone and averaging. Part 2. Shoreline boundary conditions for wave-averaged models, J. Fluid Mech., vol. 458, pp. 269-281

Mellor, G.L., 2005. Some consequences of the three-dimensional currents and surface wave equations. Journal of Physical Oceanography 35, 2291–2298.

Sanford, L. P., 2008. Modeling a dynamically varying mixed sediment bed with erosion, deposition, bioturbation, consolidation, and armoring. Computers and Geosciences, in press.

Svendsen, I.A., 1984: Mass flux and undertow in a surf zone, *Coastal Engineering*, 8, 347-365.

Traykovski, P., P. Wiberg, and W. R. Geyer (2007), Observations and modeling of wave-supported sediment gravity flows on the Po prodelta and comparison to prior observations from the Eel shelf, *Continental Shelf Research*, 27, 375-399.

Warner, J.C., Sherwood, C.R., Signell, R.P., Harris, C.K. and Arango, H.G., 2008a. Development of a three-dimensional, regional, coupled wave, current, and sediment-transport model. Computers & Geosciences, 34: 1284-1306.

Warner, J.C., Perlin, N. and Skyllingstad, E.D., 2008b. Using the Model Coupling Toolkit to couple earth system models. Environmental Modelling and Software, 23: 1240-1249. doi:10.1016/j.envsoft.2008.03.002 .

PUBLICATIONS

The following publications represent work supported by CSTMS or use code and tools developed as part of CSTMS.

Bever, A.J., Harris, C.K., Sherwood, C.R. and Signell, R.P., submitted. Deposition and flux of sediment from the Po River, Italy. Marine Geology. [refereed]

Blaas, M., C. Dong, P. Marchesiello, J.C. McWilliams, K.D. Stolzenbach, 2007: Sediment transport modeling on Southern Californian shelves: A ROMS case study. *Contin. Shelf Res.* 27, 832-853. [refereed, published]

Dong, C., E.Y. Idica, & J.C. McWilliams, 2008: Circulation and multiple-scale variability in the Southern California Bight. *Prog. Oceanography,* submitted. [refereed]

Ferré, B. and Sherwood, C.R., submitted. Sediment transport on the Palos Verdes shelf, California. Continental Shelf Research. . [refereed]

Ganju, N.K., and Schoellhamer, D.H., 2007, Calibration of an estuarine sediment transport model to sediment fluxes as an intermediate step for robust simulation of geomorphic evolution. Continental Shelf Research, doi:10.1016/j.csr.2007.09.005. [refereed, published]

Haidvogel, D.B. et al., 2008. Ocean Forecasting in Terrain-following Coordinates: Formulation and Skill Assessment of the Regional Ocean Modeling System. Journal of Computational Physics, 227: 3595-3624. 10.1016/j.jcp.2007.06.016 [refereed, published]

Harris, C.K., Sherwood, C.R., Signell, R.P., Bever, A.J. and Warner, J.C., 2008. Sediment dispersal in the northwestern Adriatic Sea. Journal of Geophysical Research, in press. [refereed, published]

Hsu, T.-J., Ozdemir, C. E., Traykovski, P. A., High resolution numerical modeling of wave-supported gravity-driven fluid mud transport, J. Geophys. Res., submitted. [refereed]

Marieu, V., Bonneton, P, Foster, D.L., and Ardhuin, F., 2008, “Modeling of Vortex Ripple Morphodynamics”, *Journal of Geophysical Research*, in press. [refereed, published]

Rinehimer, J.P., Harris, C.K., Sherwood, C.R. and Sanford, L.P., 2008. Sediment consolidation in a muddy, tidally-dominated environment: model behavior and sensitivity. Proceedings of the Estuarine and Coastal Modeling Conference, in press. [refereed, published]

Sanford, L.P., 2008. Modeling a dynamically varying mixed sediment bed with erosion, deposition, bioturbation, consolidation, and armoring. Computers and Geosciences, in press. [refereed, published]

Signell, R.P. et al., 2008. Collaboration tools and techniques for large model datasets. Journal of Marine Systems, 69: 154-161. doi:10.1016/j.jmarsys.2007.02.013. [refereed, published]

Warner, J.C., Butman, B. and Alexander, P.S., 2008. Storm-driven sediment transport in Massachusetts Bay. Continental Shelf Research, 28: 257-282. doi:10.1016/j.csr.2007.08.008 . [refereed, published]

Warner, J.C., Perlin, N. and Skyllingstad, E.D., 2008. Using the Model Coupling Toolkit to couple earth system models. Environmental Modelling and Software, 23: 1240-1249. doi:10.1016/j.envsoft.2008.03.002 . [refereed, published]

Warner, J.C., Sherwood, C.R., Signell, R.P., Harris, C.K. and Arango, H.G., 2008. Development of a three-dimensional, regional, coupled wave, current, and sediment-transport model. Computers & Geosciences, 34: 1284-1306. doi:10.1016/j.cageo.2008.02.012. [refereed, published]

Vionov, A.A. et al., submitted. Integrated Environmental and Earth Systems Modeling: a Community Approach. Science, submitted to the Policy Forum. [refereed]

Uchiyama, Y., J.C. McWilliams, & J.M. Restrepo, 2008: Wave-current interaction in nearshore shear instability analyzed with a vortex-force formalism. *J. Geophys. Res.*, submitted. [refereed].